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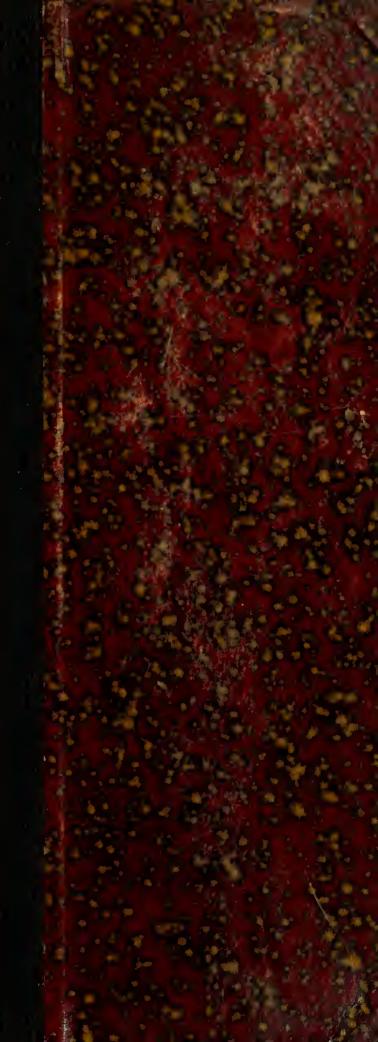
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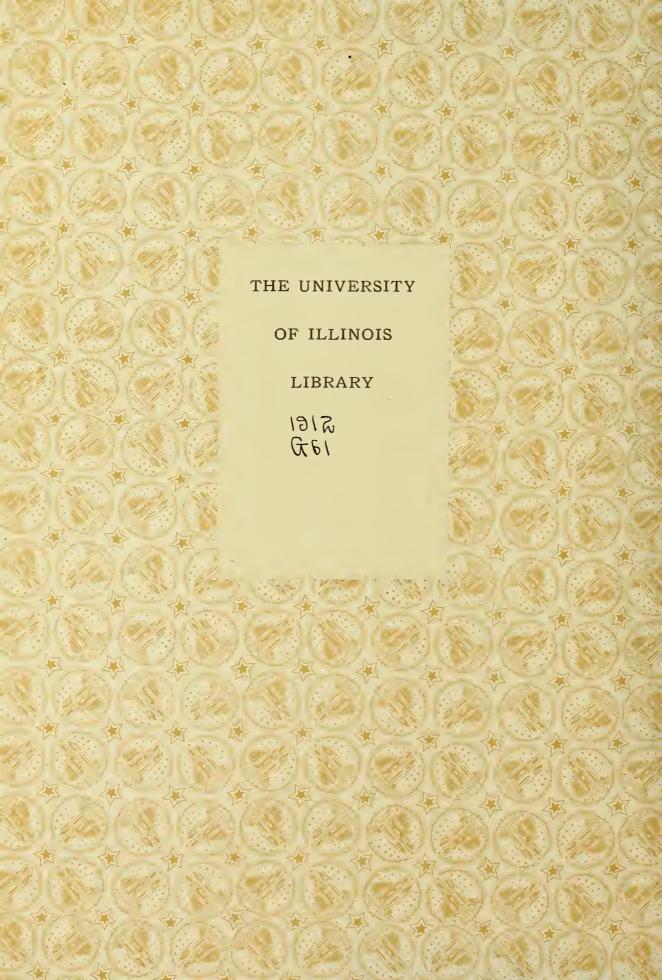
Strength of Thermit Welds

Mechanical Engineering

B. S.

1912









# DETERMINATION OF STRENGTH OF THERMIT WELDS

BY

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## THESIS

FOR THE

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IN

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-

## DETERMINATION OF THE STRENGTH OF THERMIT WELDS

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#### Introduction.

1. <u>Discussion</u>. - For certain classes of welding a comparatively new and successful method is the Thermit Process. It was invented by Dr. Hans Goldschmidt of Essen, Germany, and is developed by the Goldschmidt Thermit Company.

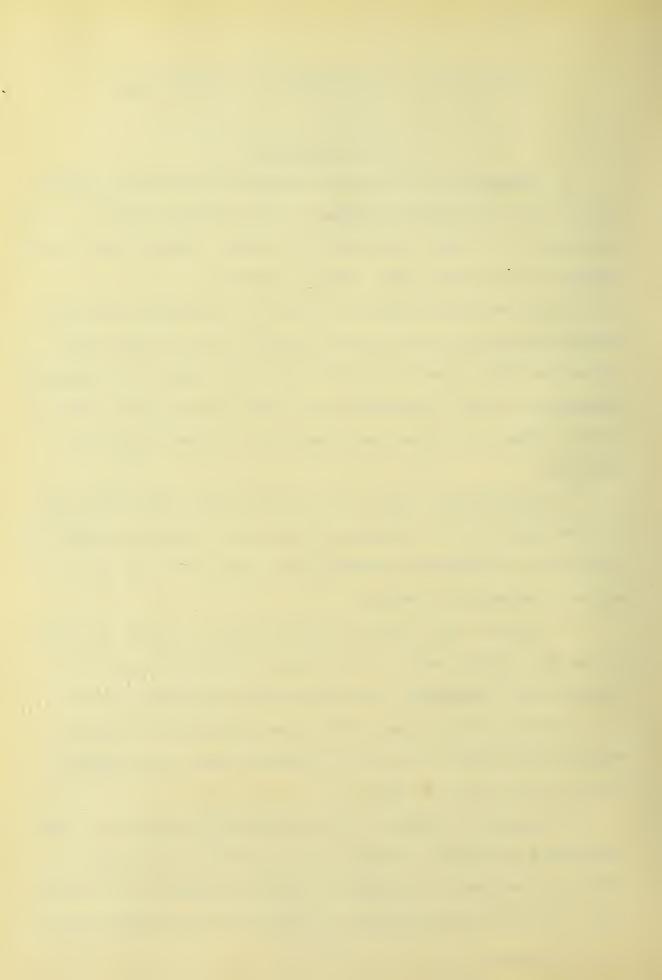
In the welding process, a mixture of aluminium and ironoxide is ignited. The aluminium reduces the iron oxide and
gives free iron, generating sufficient heat-about 2500 degrees
Centigrade-to make the molten iron steel. This molten steel is
poured around the broken part and casts a joint around the
fracture.

Dr. Goldschmidt began his investigations about 1895 but did not announce his discovery until 1898. Frevious to 1895, the price of aluminium prohibited the thought of its use in any such commercial process.

2. Object. - The object of this thesis is to get practice in making thermit welds; to determine the efficiency of the annealed and unannealed, and the turned and unturned weld.

The text of the thesis will give the theory of thermit welding, and show the principle applications of the welding and the other uses of thermit.

3. Meaning of Thermit. - The Goldschmidt Thermit Co., manufacturers of thermit, define it as follows: A "Thermit" is a mechanical mixture of a metallic oxide, sulphide, or chloride, with finely divided aluminium in such proportions that the al-



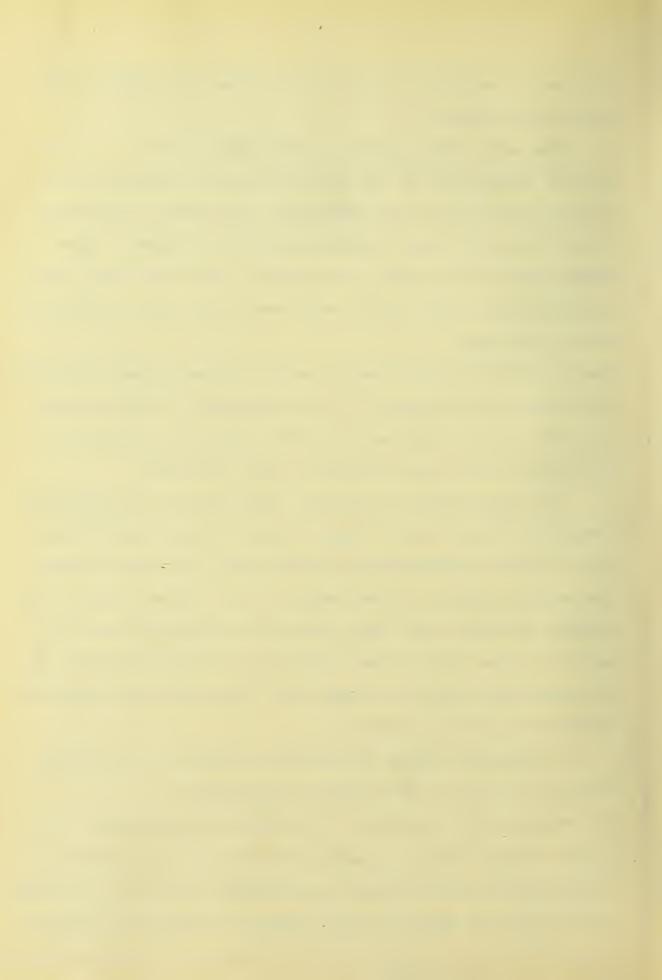
uminium, on reaction, will entirely reduce the metallic element in the oxide.

The most common thermit and the one with which we will deal in this thesis is the welding compound consisting of a mixture of aluminium and iron oxide. The general impression that this is the only thermit is erroneous. There are many others, some of which are very useful, both commercially and scientifically, and will be mentioned later, while others are not so important.

The foundation for the thermit reaction lies in the attraction of aluminium for oxygen. If this attraction is much greater than that of the other metal for the oxygen the reaction is very rapid with a large amount of heat generated.

If this attraction is small, the reaction is slow or may require artificial aid to carry it on with very little evolution of heat. The ordinary iron oxide and aluminium thermit, the welding mixture, is an example of the former class of fast burning thermits, very large quantities completing their reaction in less than one half minute at a high temperature. A tantium-thermit must be aided by the iron oxide and aluminium thermit to give any reaction.

4. Chemical Action.-The chemical formula for the iron-thermit reaction is  $8AI + 3Fe_3O_4 = 9Fe + 4AI_2O_3$ Expressing this in weights it is, 217 parts aluminium - 732
parts of magnetite = 540 parts of metallic iron - 409 parts of aluminium oxide or slag. Approximately 3 parts of aluminium and 10 parts of magnetite will produce on reaction 7 parts of

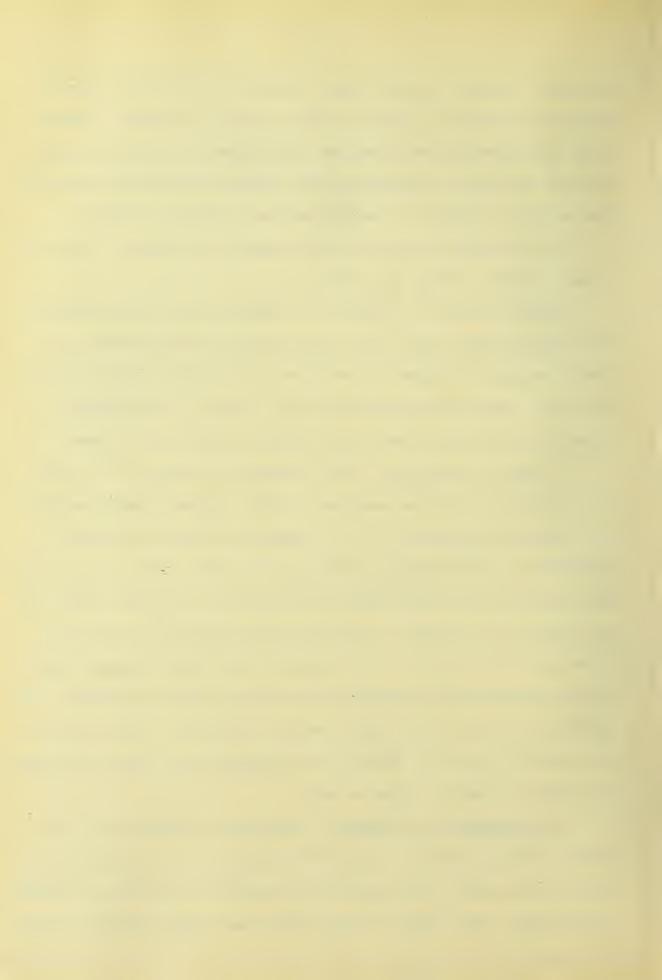


metallic iron and 6 parts slag. In the earlier days of manufacture of thermit, hematic oxide was used instead of magnetite. The chemical reaction was then:  $2AI + Fe_2O_3 = AI_2O_3 + 2Fe$  In this reaction the liquid steel produced represents one half the original thermit by weight and one third by volume.

The probable reason for the change in the oxide is to give a less violent acting substance.

Thermit cannot be ignited by heating but if the reaction is started in one place the temperature of the reaction is great enough to ingite the whole mass. To start the reaction ignition powder, which can be set off with a parlor match, (commonly aluminium powder and barium oxide) must be used.

- 5. Heat of Reaction. The Goldschmidt Thermit Co. gives the temperature of the reaction as 3000 degrees Centigrade or 5400 degrees Fahrenheit. J. W. Richards in the the Electro-Chemical and Metallurgical Industry for June, 1905, calculates the temperature as 2694 degrees Centigrade. M. Fery, using his new radiation pyrometer, found the temperature of the liquid steel as it flowed from the crucible to be 2300 degrees. This difference could be accounted for by an allowance made for the chilling effect of the walls of the crucible. Since the melting point of steel is roughly 1350 degrees Centigrade, the thermit steel is nearly twice as hot.
- 6. Appearance of Thermit. Commercial thermit is a mixture of fine, granular aluminium with less fine, granular magnetic iron scale. The aluminium is about the fineness of granulated sugar; the scale is like coarse sand. The magnetic oxide



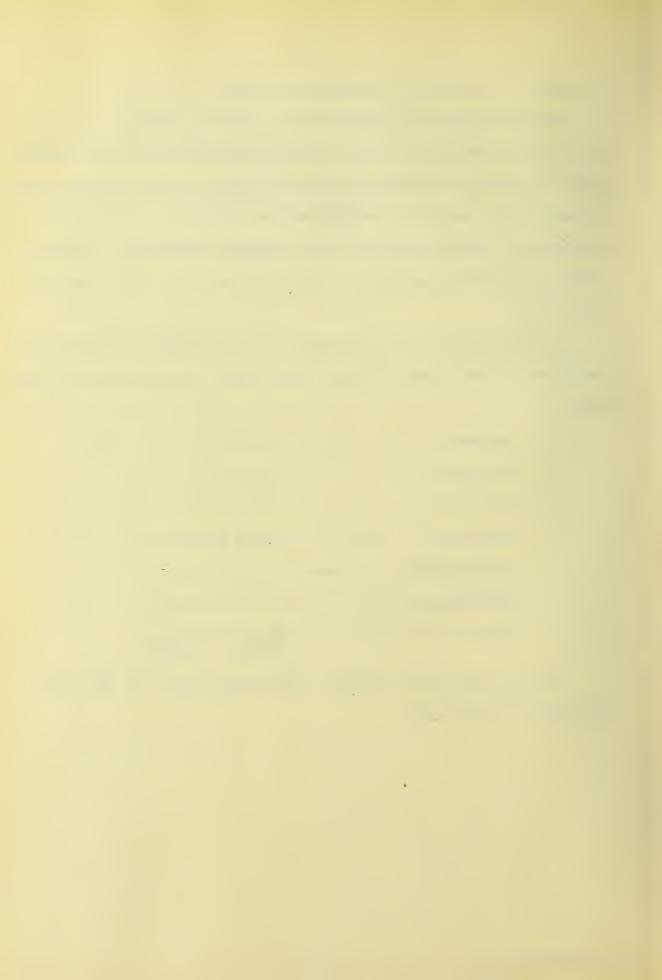
is made of granulated rolling-mill scale.

The aluminium is powdered by a secret process. It can be powdered by heating to 600 degrees Centigrade, at which temperature it becomes brittle and can be ground between rolls. Another way is to blow air through red hot aluminium, thus partly oxidizing it. After cooling to 600 degrees Centigrade, it can be ground, the oxide helping to separate themetal into fine granules.

7. Composition of the Product. - The following average composition of the thermit steel in per cent is given by the Company.

Carbon0.05	to	0.10
Manganese0.08	to	0.10
Silicon0.09	to	0.20
Sulphur0.03	to	0.04
Phosphorus0.04	to	0.05
Aluminium0.07	' to	0.18
Iron99.64		99.33 100.00

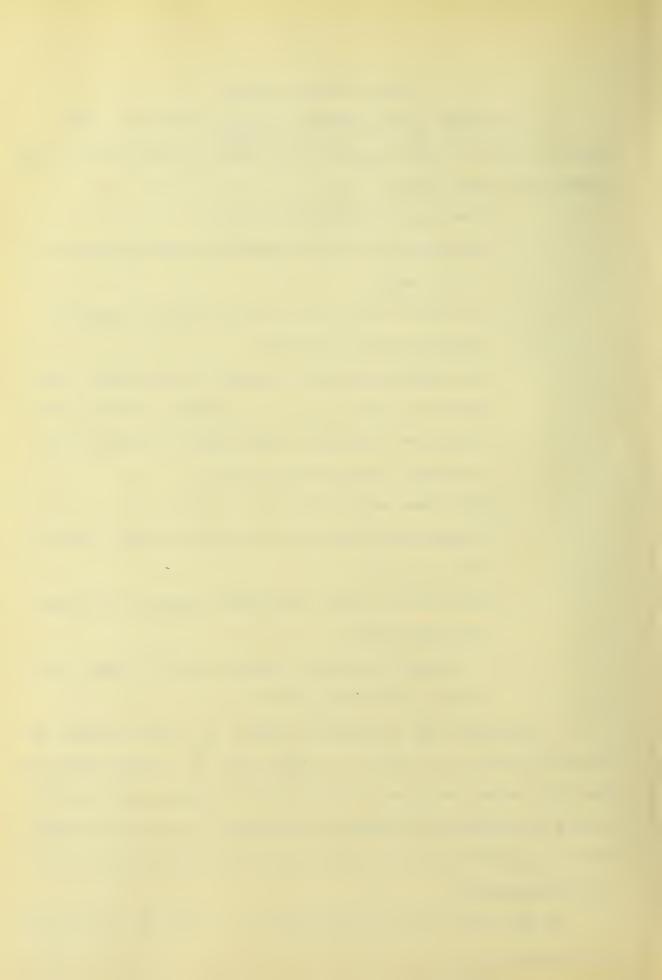
To give this pure product, the constituents of the thermit must be very pure.



#### The Welding Process.

- 8. <u>Discussion of the Welding Process</u>. The principal points in favor of and against the thermit welding process are summarized briefly thus:
  - 1. The apparatus is very simple.
  - 2. Especially skilled operators are not required to do the work.
  - Fractures difficult of access may be repaired while still in position.
  - 4. Time and money may be saved in most repair work, especially with large or irregular shaped parts.
  - 5. At present the most common uses of thermit are in repair work and rail welding.
  - 6. Only iron and steel can be welded.
  - 7. Intense local heating of parts in large pieces often occurs.
  - 8. The cost is often prohibitive though much lower than forge work.
  - 9. It cannot be applied commercially to small piece welding and manufacturing.
- 9. Preparing the Fracture to Weld. The metal around the fracture should be cleaned by emery cloth or an emery wheel so that the molten metal will stick to the outside. The fracture should be opened by chipping or drilling to allow the thermit steel to penetrate completely through the break and give complete amalgation.

If the part is to be welded while in positon in a machine,

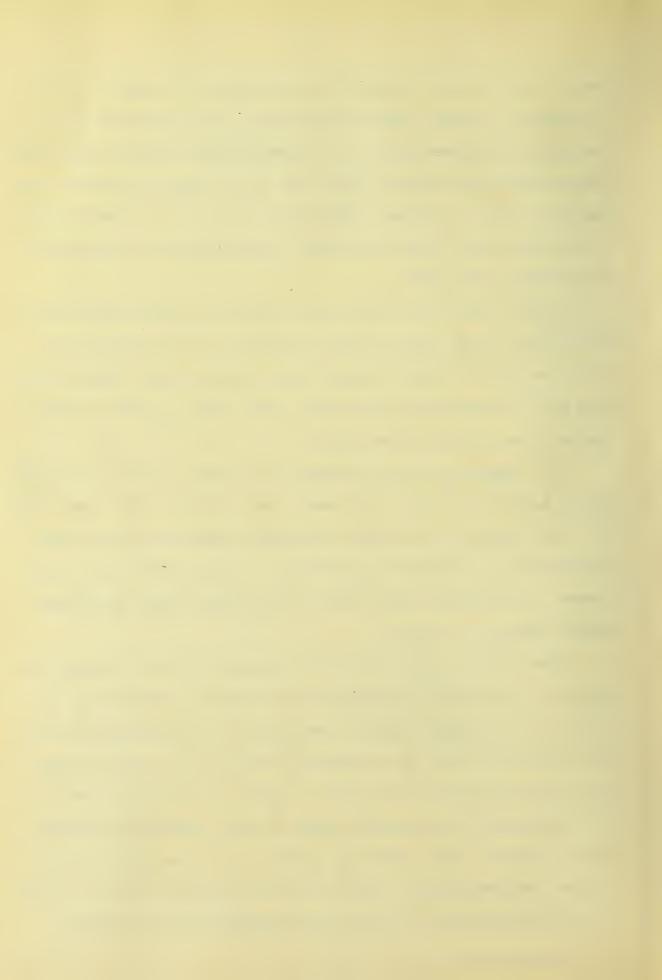


room to make a mold around the fracture must be made, even if necessary to remove obstructing parts. The piece should be put in perfect alignment and, if to have a fixed length after welding, punch marks made on each side of the fracture within convenient reach of trammel points and yet so as to come outside of the mold box. This will allow true alignment at the end of the welding operation.

Parts like locomotive frames should be jacked open about one fourth of an inch or less depending on the size of the stock and width of the thermit steel collar cast. This will allow for contraction as the frame cools. Fig. 1 shows a frame jacked open ready for the mold.

10. Construction of the Mold. The best material for making a mold is one part fire sand, one part good fire clay, and one part ground fire brick, thoroughly mixed while dry, and moistened just enough to pack well. If the ground fire brick cannot be obtained, equal parts of good fire clay and clean sharp sand may be used.

The thermit steel should not be poured directly upon the pieces to be welded, by the gate in the mold should lead the metal to the lowest point of the mold, let it rise up through and around the part to be welded, and on into a large riser. The mold must allow for a band or collar of thermit steel to be cast around the fractured ends of the pieces to be welded. As the thermit steel comes in contact with the metal, it dissolves and amalgamates itself with the welding pieces, forming a reinforcement which adds to the strength of the original



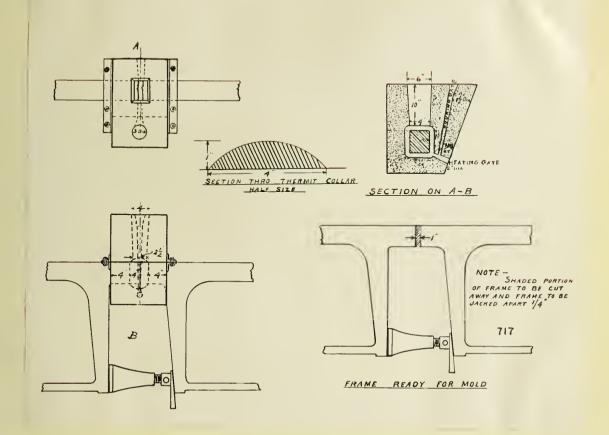


Fig. 1. Method Employed in Welding Locomotive
Frame Broken in Jaw.

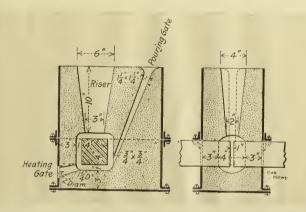


Fig. 2. Typical Thermit Mold, Showing Space Left for Collar, Gates and Riser.



piece and should not be machined from more than one or two sides except in cases of necessity.

This reinforcing band or collar should resemble in crosssection approximately the segment of a circle, the thickest
part directly over the fracture and slping gradually toward
the edges. It should overlap the edges of the fracture at least
an inch and much more on large welds. In Fig. 1 is shown the
general dimensions of a mold with riser and gates and method
to be employed in welding a locomotive frame broken in the jaw.
The cross section of the collar is also shown.

Since two repairs are seldom alike, the reinforcing collar pattern may be made of yellow wax, thus saving the time and expense of making a wooden pattern.

Frovision must be made in the mold for removing the wax.

For this purpose an opening is left at the lowest corner of the mold. The wax can be melted and allowed to flow out through this opening and then the flame directed on the metal to preheat it for the weld. This opening is also shown in Figs. 1 and 2.

The pattern for the pouring gate and riser may be easily made of wood. Their volume should equal that of the reinforcement or collar cast around the fracture, since the first thermit steel running into the mold is chilled by the mold and frame which, even when preheated, has a much lower temperature. This chilling can only be overcome by allowing enough thermit steel to force the chilled portion up into the riser, heating the metal as it rises, and replacing it by fresh thermit at



practically the full temperature of the reaction.

11. Description of Crucible and Other Apparatus. The crucible for the thermit welding is an inverted cone shaped affair that taps at the point or bottom. It is constructed especially for the thermit process and is so designed that the thermit steel can be drawn off before the slag.

It has a rounded, removable iron cover which is placed over the top as soon as the charge is ignited to prevent spattering and loss of heat. The crucible is supported on a tripod or may be slung from a crane or overhead arm.

The body of the crucible is of pressed steel, lined with a tar magnesia filler. When newly lined, the crucible is baked six hours. The magnesia is more refractory than the silica, and it will not unite so readily with the thermit steel, thus leaving the steel basic.

The tap hole is the vital part of the crucible. It must remain fluid-tight until tapped and then must withstand the rush of the thermit steel. The bottom of the crucible holds a hard burnt cylindrical stone, shown at E in Figs. 3 and 4. This is placed in the crucible before the lining is put into place. A smaller conical magnesia stone or thimble (F) fits into a tubular opening in E. The thimble is hollow and provides the channel through which the thermit steel is poured. This outlet must not be more than one half inch in diameter. After a few runs have been made the thimble should be replaced with a new one. It is removed by knocking upward and a new thimble, folded around with a layer of uncreased paper, put in its

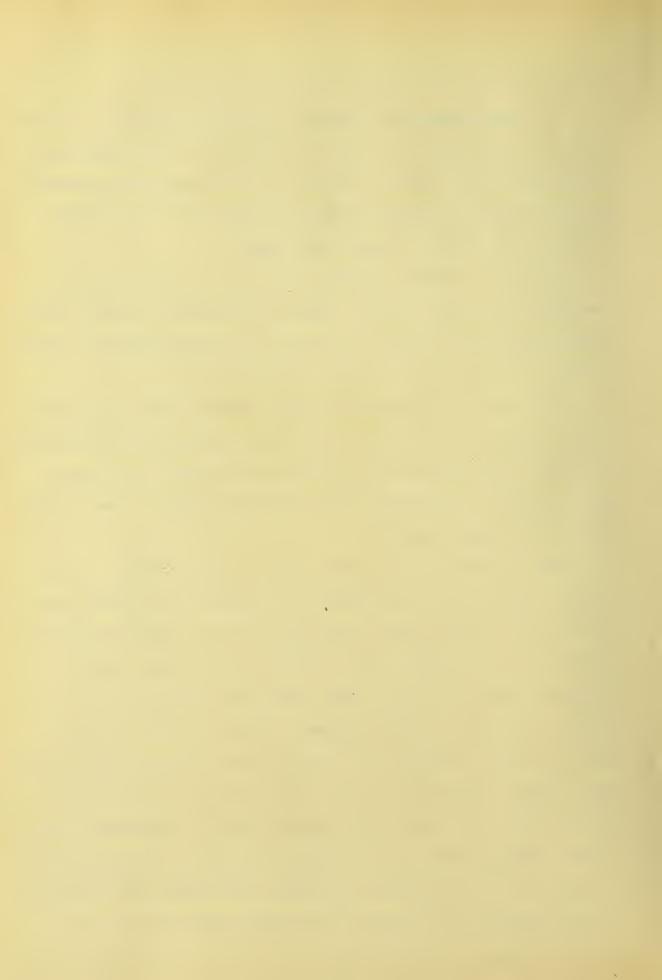




Fig. 3. Automatic Crucible. The Ordinary Type.



Fig. 4. Sectional View of Crucible with Plugging
Material in Place.



Fig. 5. Flat Bottomed Crucible (so-called "Special Crucible.



place. An iron tapping pin shown in Fig. 4, having a long shank and a flat head, is dropped into the hole in the thimble. Its head acts as a plug to the channel. An aspestos washer is placed on the head of the tapping pin, next an iron washer, and on top an inch of silica sand is poured. This is called "plugging" the crucible, and the materials used in the process, "plugging materials".

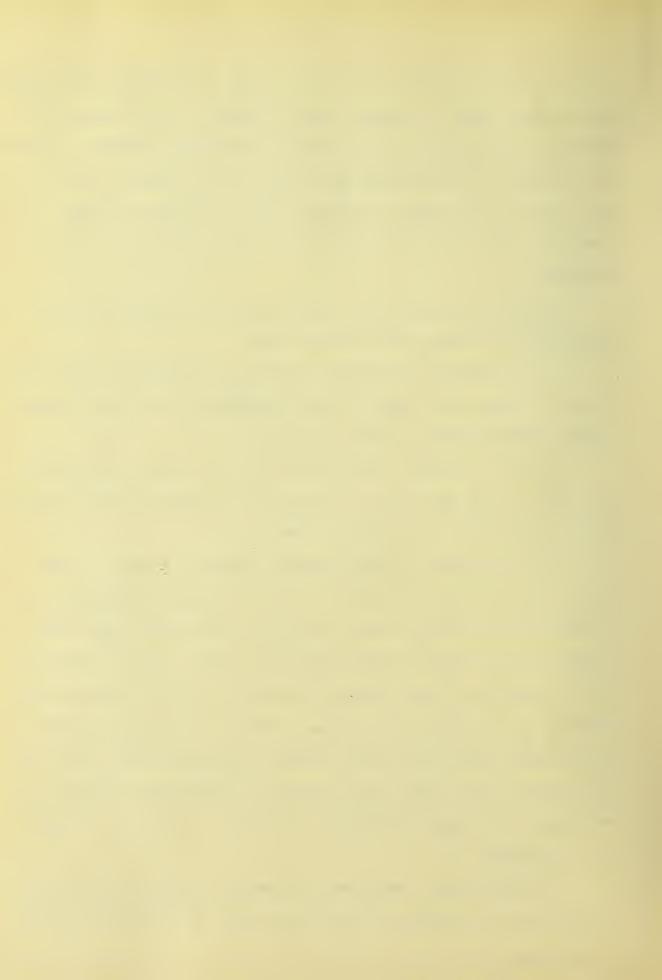
This makes a plug that will last about a minute, long enough for the reaction to take place.

A new supply of plugging material is needed for each reaction a new thimple every eight or ten reactions; and a new crucible lining every twenty or more reactions.

A form of special cruciple is shown in Fig. 5. This type is used in pipe welding, etc. where it is desired that the slag shall pour pefore the thermit steel.

yellow wax is used to make the collar pattern, the weight of thermit to be used is easily found. In this case, great care should be exercised to have the entire space between the ends of the fracture filled with wax as well as all the other space that is to be filled with thermit steel. By weighing the wax both before and after this operation, the difference will give the weight of wax used this weight in pounds multiplied by 32 will give the proper quantity of thermit, in pounds, required for the weld.

In calculating the amount of thermit required for any particular weld in advance, first calculate the contents in cubic



inches of the reinforcement and between the ends of the sections to be welded. This should be doubled to allow for the riser and gate. This number multiplied by Il gives the number of pounds of thermit to be used. Nine ounces of thermit produce one cubic inch of thermit steel.

when more than ten pounds of thermit are used it is necessary to mix steel punchings not exceeding one half inch in diameter, or clean particles of steel into the thermit powder. This decreases the violence of the reaction without interfering with the efficiency of the weld. For from 10 to 50 pounds of thermit, 10% of punching, and, for over 50 pounds as much as 15% of small mill steel rivers may be added.

An addition of 1% pure manganese (based on weight of thermit) and 1% of nickel thermit strengthen the weld materially.

In the following table, prepared by the Goldschmidt Thermit

Co., are given the ordinarily proper portions of thermit, punchings, magnesia, and nickel to be mixed with the thermit for a given cross section.

Welding Portions.

No.	Cross section	Weight of Thermit	Wt. of Funch.		
	sq. in.	los.	lbs.	OZ.	OZ.
1	6	40	6.	6.5	6.5
2	9	45	6.75	7.5	7.5
3	10.5	50	7.5	8.	8.
4	12	55	8.25	9.	9.
5	16	65	9.75	16:5	10.5
6	20	70	10.5	11.	11.
7	25	75	11.25	12.	12.
8	36	85	12.75	14.	14.
9	36	90	13.5	15.5	15.5

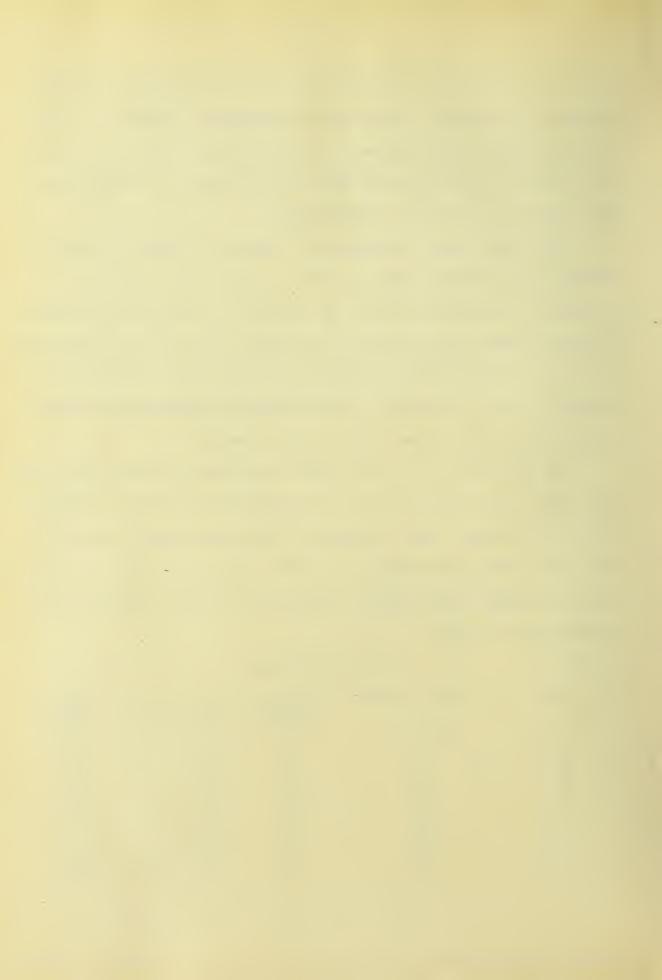




Fig. 6. Locomotive Frame in Process of Welding.

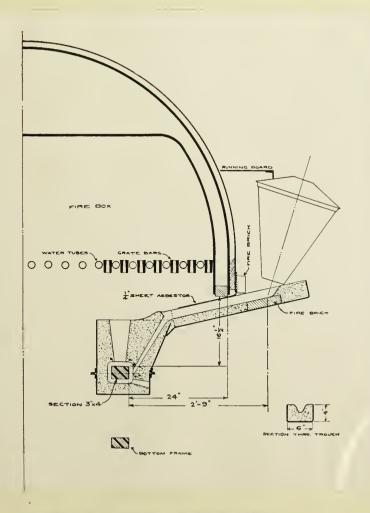


Fig. 7. Engine Frame Weld.



- 13. Charging the Crucible. The crucible is placed directly over the mold with the tap hole above the pouring gate in the mold. The plugging material is next placed in the thimble and the thermit is poured in the mold. The ignition powder is not placed in the mold until ready to ignite. Figs. 6 and 7 show a mold and crucible in position.
- pouring the charge since the cold metal and mold would cool the steel too much. In Figs. 1 and 2 was shown a mold with a heating gate. If wax has been used to form the collar pattern, it can be melted out and then the mold heated through this gate. A gas or gasoline torch should be used for heating since an oil torch is liable to deposit carbon in the mold. Two forms of heaters are shown in Figs. 8 and 9.

The iron should be neated to a bright red heat and the heating gate plugged with a dry sand core and backed with enough sand to prevent leakage. In welds like locomotive frames where one member of a double frame is welded, it is necessary to heat the other member with a torch in order to get equal expansion and contraction in both members and prevent unequal strains.

15. The Reaction. - When the mord and metal are thoroughly heated, one half a teaspoonful of ignition powder is placed on the top of the charge. With this powder are placed two or three parlor matches with their heads together, as shown in Fig. 10. Light these with another parlor match, but withdraw the hand quickly as soon as the matches have caught fire and place the

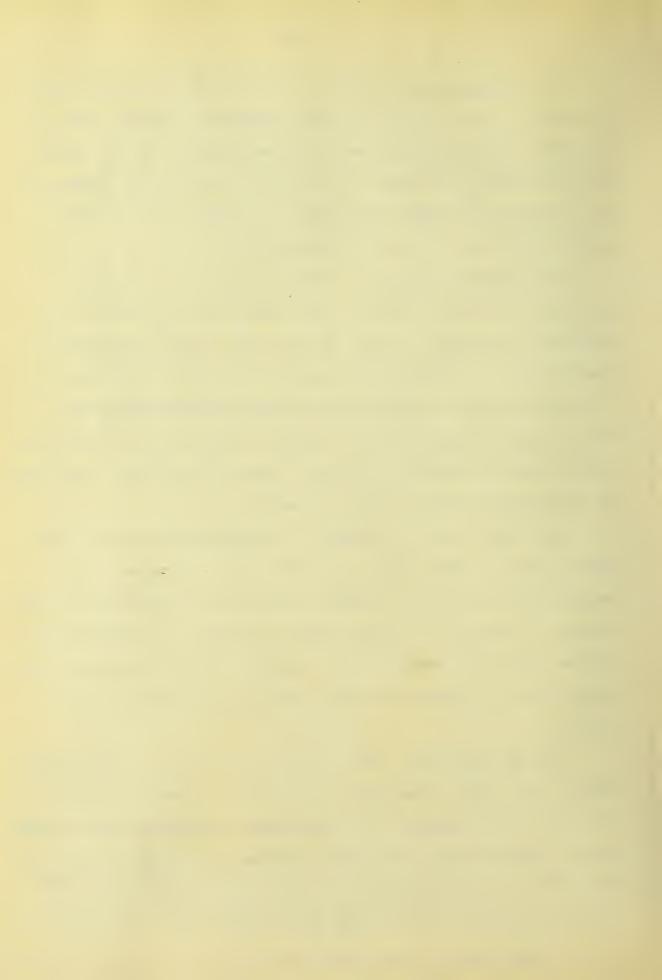




Fig. 8. Preheater Designed Especially for
Use in Connection with Thermit Welding.



Fig. 9. Buckeye Heater.



cover over the crucible.

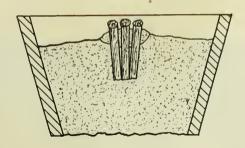


Fig. 10. Showing Method of Igniting Thermit.

The reaction is started by the ignition powder in one spot and travels rapidly through the mass. The reaction is completed in about 20 to 30 seconds but it is best to wait about 30 seconds more to let the slag rise to the top.

The crucible is tapped or poured by knocking the tapping pin up into the thermit steel. The pin and metal plug are melted by the hot liquid and the thermit steel runs on down into the mold.

Fig. 11 shows a thermit reaction.

16. Treatment of the Weld.- After the weld has stood for ten or fifteen minutes the mold may be knocked off. This sudden cooling makes the welded part very hard and brittle, although it may be annealed by heating and cooling slowly. The better way is to leave the weld in the mold and feed some thermit into the riser to keep it hot while the main body of the weld cools slowly. The weld then is not removed until it is thoroughly cooled.

The riser and pouring gate should be drilled off but the collar should not be removed except in cases of necessity and and then not from more than two sides of the weld.





Fig. 11. Pouring a Large Crank-Shaft Weld. Photograph Taken as the Slag Was Overflowing Mold.



The weld should show perfect amalgation of the thermit steel and the iron. Blow holes show the presence of slag in the thermit caused by not allowing sufficient time for the slag to rise to the top of the crucible, at the end of the reaction, before the crucible was tapped. If the iron was not sufficiently preheated, or the ends dirty, the collar is apt to be loose and make an imperfect weld.



## Various Uses of Thermit

Introduction. - There are a great many commercial processes to which thermit is applied. The following pages contain a discussion with illustrations of the various applications of thermit.

17. Rail Welding. - In electric railway service, the ordinary bond or connection between the rails does not give a very good electric connection. For street railway service it has become customary to weld the ends together by the aid of thermit.

In American practice the entire rail is welded by carrying the reinforcing collar entirely around the section and
leading the riser from the top of the rail. The riser and pouring gates are then cut off and ground down flush with the surface of the rail. Finished rails are shown in Figs. 12, 13, and
14.

The European practice differs materially from the above in that they carry the thermit steel only around the base and flange of the rail but allow the superheated slag to flow into a space surrounding the head. This slag brings the head of the rail to a welding temperature at which time the ends of the rails are squeezed together by means of powerful clamps shown in Figs. 15, 16, 17, and 18, and a butt weld effected. This leaves a slight upset at the end of the operation but it is only necessary to do a little grinding to put the surface in perfect condition.

The higher carbon content of the American rail makes it extremely difficult to weld by the butt weld method. The low

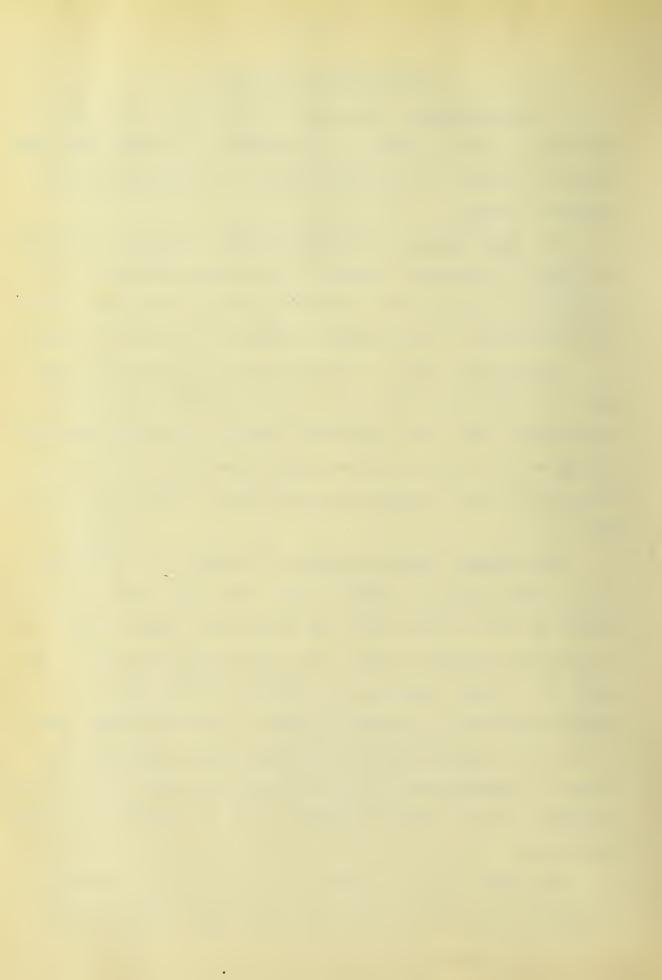




Fig. 12. Finished Rail Joint After Being Ground.

The White Appearance on the Head Is Due to Reflection of Light from the Polished Surface

Produced by Grinding.





Fig. 13. Rail Weld.



Finished Weld on Rail Showing Reinforcement Around Sides and Base

Fig. 14. Rail Weld.





Fig. 15. Welding Rails at Copenhagen, Denmark.

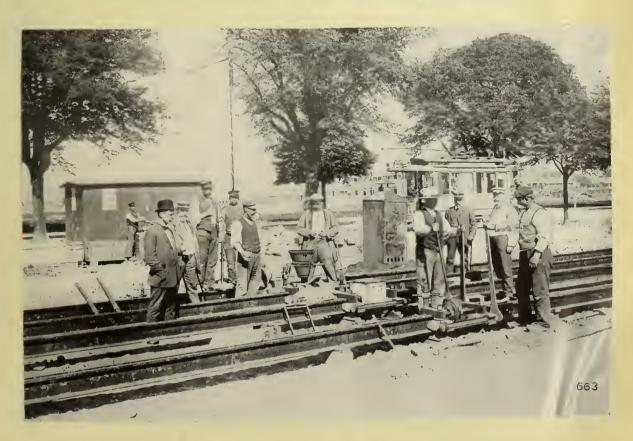


Fig. 16. Butt Rail Welding.

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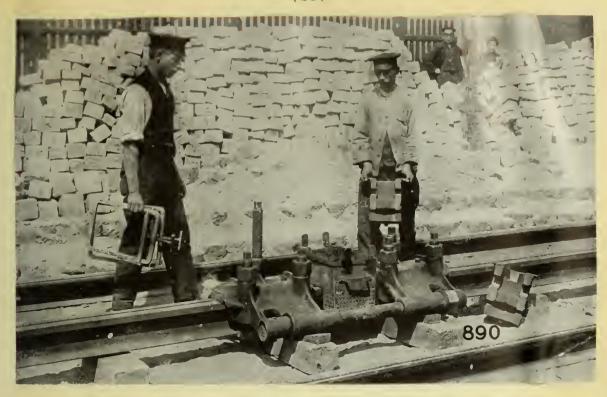


Fig. 17. Rail-Welding in Europe.

Preheating and About to Assemble the Mold.



Fig. 18. Rail-Welding in Europe.

Everything Ready for the Thermit Reaction.

Annual Prince of the Park of t

carbon European rails give satisfactory results with this meth-

The life of the track is measured by that of the rail, and the life of the rail by that of the joint. The thermit welded joint not only gives longer life but greater strength and electric conductivity.

In Manchester, England, in three years only 0.3% of the joints broke out of 7000 welds. On the Leeds City Tramway, only 3% out of 11,000 joints-60 miles of track-broke in 8 years. This includes their first welds, but on their later work the percentage of breakage does no exceed 0.7%.

A large advantage in making a compromise joint lies in using thermit. This joint, the union of two different kinds of rails is very difficult to make with ordinary methods. Fig. 19 and Fig. 20 are both illustrations of compromise joints.

Another method of welding rails is just casting a rib on the lower flange. Sometimes a copper bond is welded across from the lower flange of one rail to the next. This gives free expansion of the joint but a good degree of conductivity. The fish plate is still necessary for the strength. Fig. 21 is an illustration of Clark joints which are used extensively in interurban service.

18. Butt Pipe Welding. - Often, in connecting pipe lines, it is desirable to join pipe ends without making a joint. Examples of this kind of work are pipes for ammonia, (refrigorating systems), compressed air, hydraulic work, deep well lining, steam pressure and pipe coils.





Welded Compromise Joint Between Bridge Rail and 9-In. Trilby Rail

Fig. 19



Welded compromise joint between 21/2-inch stringer rail and 7-inch trilby rail

Fig. 20



Completed Clark joint

Fig. 21



The weld in this case is not made by casting a collar around the joint but the ends of the pipe are heated by the thermit to a welding temperature and forced together by large clamps.

The ends of the pieces to be welded are filed and then butted carefully together between clamps as shown in Fig. 22. Around the joint is placed a cast iron mold--Fig. 23--in two parts, the upper one having a narrow gate to admit the hot slag and metal.

The thermit is ignited in a flat bottomed crucible held in a pair of tongs. After the reaction the slag fills the upper part of the crucible and has three times the volume of the superheated liquid steel which collects at the bottom when the whole mass is liquified.

The liquid mass is then poured into the opening of the mold. The slag flowing first, will adhere in a thin layer to the walls of the mold and to the surface of the pieces to be welded, and will protect them from contact with the liquid steel which runs in last. After waiting for the ends to soften, the clamps are drawn up and effect the weld by squeezing together the plastic ends of the pipe. On chilling, the layer of slag is easily knocked off. Fig. 24 shows a mold being poured. Fig. 25 shows a mold for welding vertical pipe.

The following table gives the cost per joint of welding portions and rent, appliances for butt welding various sizes of pipes, assuming that 100 joints are welded and the clamps are rented at five cents per joint.



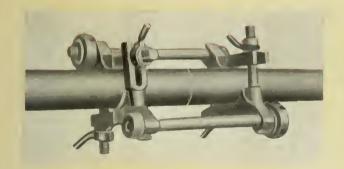


Fig. 22. Clamp in Position.



Fig. 23. Cast Iron Mold

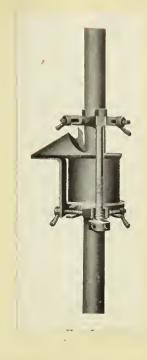


Fig. 25.

Vertical Pipe Welding.



Fig. 24. Welding 5-inch Pipe in a Trench.



Cost of Welding Pipe Fer Joint

Size of Pipe		Cost per joint	
in inches	Standard	Extra Heavy	Double Extra
	Pipe	Pipe	Heavy Pipe
• 5	\$0.53	\$0.58	
. 75	0.58	0.63	
1.00	0.74	0.84	\$1.05
1.25	0.89	0.99	1.40
1.5	1.00	1.20	1.86
2.	1.05	1.56	2.75
2.5	1.56	2.76	3.67
3.	2.12	3.67	
3.5	3.12	4.17	
4.	3.43	4.25#	

#Mold made of dry sand instead of cast iron.

Steel bars can be butt welded in the same way.

19. Repairing Flaws and Blow Holes. - For small flaws and blow holes the pouring cup method, Fig. 26, may be used. The flaw should be chipped out clean and the casting heated to a red heat.

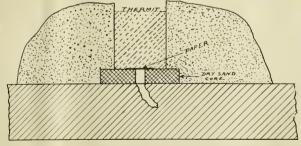


Fig. 26. Pouring Cup.

The pouring cup is placed around the flaw. In the bottom of the cup is placed a dry sand core with an opening into the flaw. This opening is covered with a piece of asbestos paper, the thermit poured on top, and ignited.

The thermit steel runs down into the flaw and fills it.

The part projecting out should be ground off and not chipped away.

If the flaw is large a crucible may be used, tapping dir-



ectly into the pouring cup. Sometimes a boss may be welded to a piece of iron as shown in Fig. 27, by using the crucible and pouring cup.



Fig. 27. Large Boss Weld Made To 3/8" Steel Plate.

20. <u>Use in Foundry</u>. - Thermit is used in a foundry to liven up molten iron, to make semi-steel, etc. In livening up the molten iron a can of thermit and ignition powder is placed on an iron rod and held down in the ladle. Cast iron will not ignite the thermit but must have ignition powder. Fig. 28 shows effect of thermit on fluidity of iron.

The semi-steel is made by putting in hot steel shavings, borings, etc., and a can of this thermit with the molten gray iron. As much as 4 or 5 per cent of steel may be introduced into the ladle.

Titanium can be introduced into the metal to purify it, by using a Titanium Thermit can. In large castings, small cans are inserted into the risers to keep the metal a liquid until the main body of the casting is cool. Fig. 29 and Fig. 30 show a thermit can fastened to a rod ready for inserting into a ladle of iron or a riser.

21. Reducing Piping in Ingots. - Thermit is also used to prevent piping in steel ingots. A can of thermit, if inserted into the top of the ingot generates enough heat to remelt the upper portion of the ingot and keep it warm while the main





Fig. 28. Experiments with Heating Thermit To Show Effect Of Increasing Temperature and Fluidity Of Dull Liquid Iron.

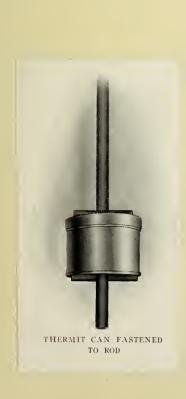
Bar 1. Fluidity Wedge Fattern 18x3x1.5 inches.

Bar 2. Poured From Very Dull Iron Into Mold Made From Fluidity Wedge.

Bar 3. Same Metal as in Bar 2 Revived by Thermit Reaction,

Poured into Companion Mold Made from Same

Fluidity Wedge.



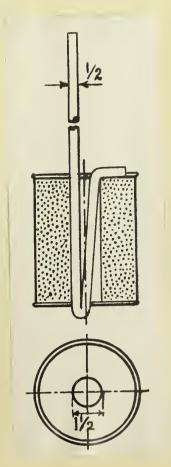


Fig. 29

Fig. 30. Sectional Drawing of Anti-Piping Can and Rod.



body of the ingot is solidifying. Figs. 30, 31, and 32 show methods of using and effects of using and not using. The cost is about 35 cents per ton of ingot.

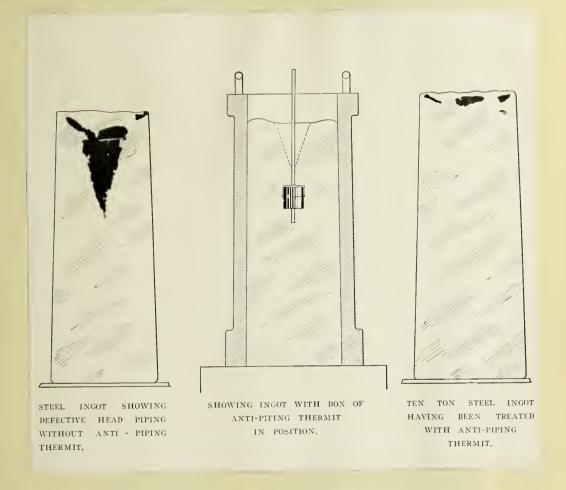


Fig. 30. Use of Anti-Piping Thermit.

22. Preparing Pure Metal. In preparing the pure metal free from carbon, aluminium mixed with the finely divided compounds of the metal acts as the reducing agent. These mixtures or thermits, when ignited, react rapidly, thealuminium displacing the metal and giving the pure metal free. As no carbon is used in the reduction, no carbon will be found in the product.

One of the most important of these pure metals thus ob-





Fig. 31. Ingots Made Without Using Thermit

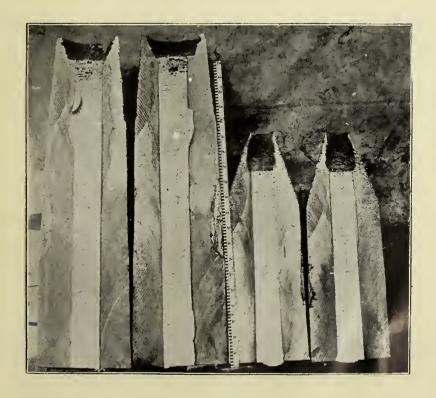


Fig. 32. Ingots Made With Thermit.



tained is ferro-titanium. It is used as a purifying agent for iron and steel because of its high affinity for oxygen and nitrogen. It also acts on sulphur and phosphorus in the iron. By removing these impurities it gives a much denser grain to the iron. About 2 or 3 pounds of the alloy per 1000 pounds of metal is the common proportion used.

Pure chromium is another thermit production which is used extensively in steel making. The advantage of using the pure metal lies in that it does not change the carbon content as would an iron alloy containing carbon. Pure manganese, made in the same way, is also used extensively in the manufacture of very hard steel. It also improves the properties and qualities of brass alloys, nickel castings as coins and medals, German silver, aluminium alloys, and copper and bronze alloys.

23. Examples of Large Welds. - Thermit welding finds one of its largest fields in making large and complicated repair welds. The following illustrations show a few of the possibilities along that line.

Figs. 33, 34, and 35 show the method used in welding an electric motor case and the finished weld. In Figs. 36 and 37 is shown a fractured bearing on a gas engine and the repair made by casting a new bearing with thermit. Another example of engine repair is shown in the fracture and repair weld on a large 14 inch crank shaft, Figs. 38 and 39.

Railroad repair work offers a large field for thermit welding. In it repairs must be made rapidly and quite often without removing the fractured piece from the engine. Figs.



WELDING ELECTRIC MOTOR CASES.



Fig. 33. Crucible and Mold Ready for Pouring.



Fig. 34. Metal Cast, Pouring Gate, and Riser.



Fig. 35. Finished Weld.





Fig. 36. Bearing of Engine Showing Both Fractures.



Fig. 37. Finished Weld

Before Cutting off Risers.





Fig. 38. Fracture in 14-in. Crank Shaft of Electrical
Unit of the Binghamton Railway Company of
Binghamton, New York.



Fig. 39. Finished Weld on Binghamton Crank Shaft
Showing Metal inRiser and Two Pouring Gates.

Shaft Machined in a Lathe Before Placing
in Service to Remove Excess Metal.



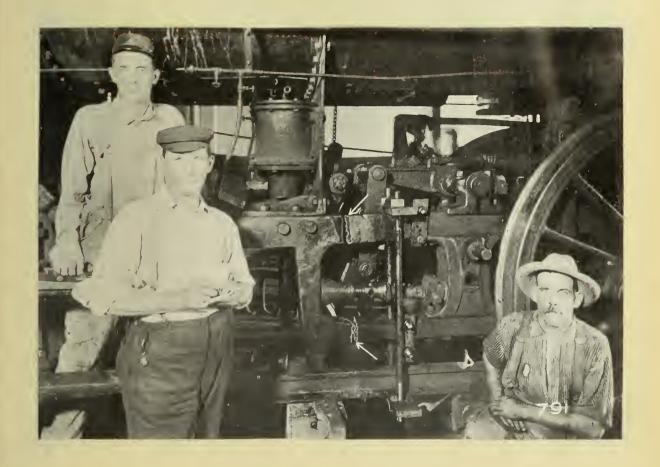


Fig. 40. Fractures in Main Frame of Engine No. 45
of the Toledo, St. Louis and Western
Railroad, Frankfort, Ind.
Cut-Out Ready for
Welding.



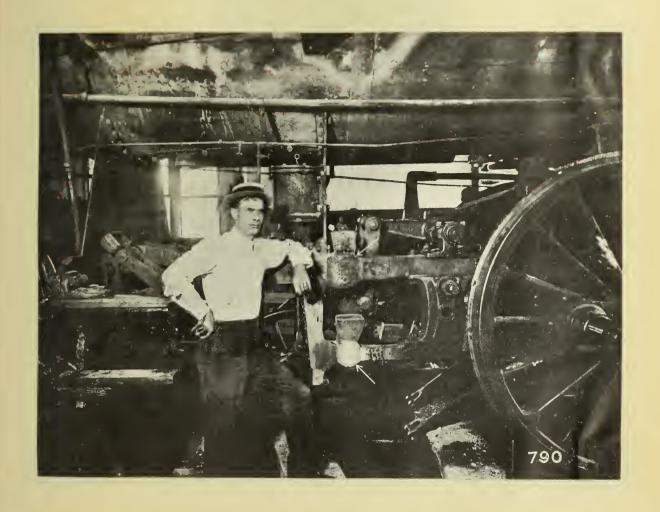


Fig. 41. Toledo, St. Louis and Western Engine No.
45 with Fractures Welded by the Thermit Process.





Fig. 42. Finished Thermit Weld on Locomotive
Frame. Reinforcing Collar on Each
Side of Frame.



Fig. 43. Showing Four Spokes Welded in Two Operations of Locomotive Driving Wheel.



Fig. 44. Locomotive Side Rods Repaired with Thermit.





Fig. 46. S. S. "Monroe C. Smith". Finished Weld Showing Metal left in Pouring Gate and Riser,

Which Was Afterwards Removed.

Weld Executed 1911.



Fig. 45. S. S. "Monroe C. Smith", U. S. Transportation Co., Cleveland, O., Showing Fracture in Sternframe

Prepared for Welding.





Fig. 47. U. S. Collier "Nero." Sternframe Welded at Brooklyn Navy Yard in Three Places, 1910.



40 and 41 show repairs made to the main frame of a loclmotive without dismantling. Figs. 42, 43, and 44 show various repairs made in a railroad shop with thermit.

Fractured stern-frames and rudder posts in large ships can easily be repaired by the aid of thermit. After the ship is dry docked it takes a very short time to execute the repair. If the fractured part had to be removed from the ship and a new one inserted it might easily require several months. Figs. 45, 46, and 47 show repairs made on ships.

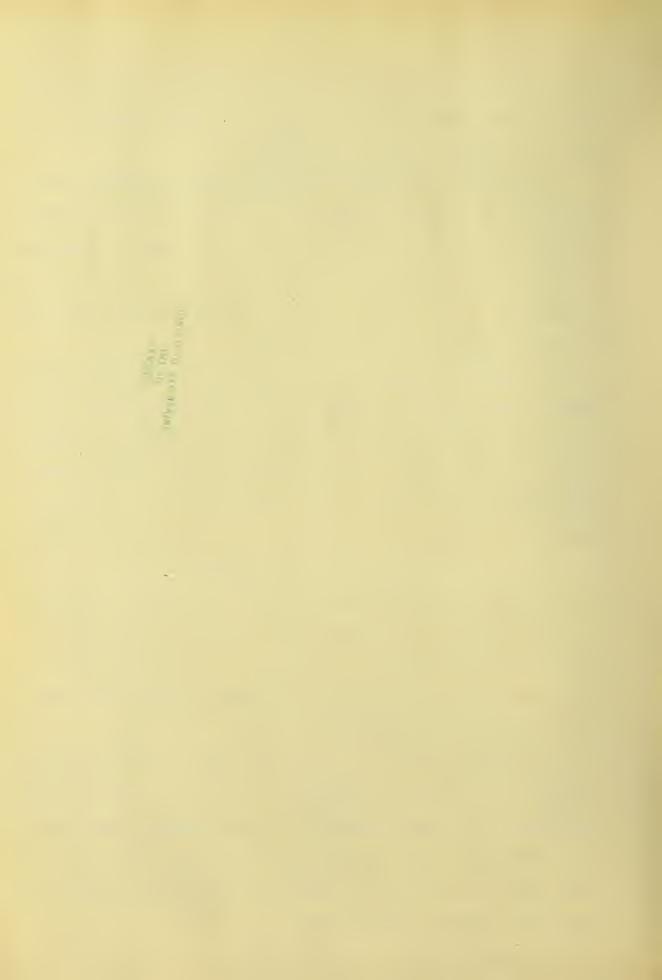
24. Tests of Welds. - As an example of a test of a large thermit weld, the author will give the following tests and give the tables of results as given by the Goldschmidt Thermit Co. Fig. 48 shows a section through a weld illustrating the perfect amalgamation of the thermit steel and the metal welded.

"Tests of Thermit Welds."

"Made at Sheffield Testing Works, Ltd., For the British Corporation For the Survey and Registry of Shipping."

"These tests were made on 5-inch by 5-inch mild steel pars which were welded together by the Thermit process. The tests were completed in July, 1909."

"It will be seen from results of tests that the maximum load applied to the Thermit welded bar was 143 tons, and to the unwelded bar 123.15 tons, showing that the Thermit welded bar was about 20 per cent stronger than the unwelded bar. The maximum stress at the place of fracture of the Thermit welded bar was 49.764 tons per square inch."



"The strength of the welded bar, with the reinforcement left on was 170 per cent. stronger than the original bar."

Tensile Tests.

Description	Size of Bar.	ULTH STRE		Contraction of area at fracture, per cent.	Extension in 2 in., per cent.	Appearance and position of fracture.	
Solid bar mild steel,.	2 in, dia,	80.5	25.6	57.1	65.0	Silky.	
"Thermit" welded bar, bulb turned down to diameter of bar.	2 in, dia.	78.8	25.1	58 4	65.0	In solid clear of weld, Silky	
"Thermit" welded bar. bulb \ left on	2 in. dia.	79.4	25.3	58 4	66.0	Do. do.	

## Bending Tests.

Description	Size of Bar	Span	Total Load, Tons	Angle Bent through	Effects
Solid bar	2 in. dia.	15 in.	10.18	180	Uncracked.
"Thermit" welded bar, bulb turned off	2 in. dia.	15 in.	10.09	46	Broken at weld.
"Thermit" welded bar, bulb left on	2 in. dia.	15 in.	17.30	125	Bent as far as practicable. Un- cracked.

							-													
		Dis-	LOAD APPLIED IN TONS AT CENTRE OF 3-FT, SUPPORTS										Maxi- inum Stress, Tons	Remarks						
Mark Description	tance Re- tween Sup-		Deflection and Set in Inches																	
		ports	Load in Tons	5	20	30	35	40	50	60	70	80	90	100	110	120	130	140	Tons	
K1	5-in. square "Thermit" welded bar		Defin . Set			.02	.06	.08	.10	.12	. 40	.80	.85	1.02	1.38	1.85	2.58	3.72	143.0	The bar broke outside the weld. Fracture, finely granular.
K2	5-in. square "Thermit" welded bar	3 feet	Defin. Set	zero	.02	.06	.08 none	.09	.11	.13	.26								71.5	Bar deflected 0.30 in Load applied, half maximum applied to Bar K1. No sign of cracking.
КЗ	5-in. square unwelded bar	3 feet	Defin. Set					.05	.10	.38	.75	1.20		2.90		6.33		• • • •	123.15	The bar continued to bend without any fur- ther increase of load, and the test was stopped after bending through an angle of 50°. No sign of cracking.
K4	5-in square "Thermit" welded bar	3 feet	Defin. Set	zero		.02	.04	.08 none	.08	.10	.22	.48	. 70	1.08	1.50	2.25	3.18			The bar broke outside weld. Fracture: Crystal- line, traces unsound. Finely crystalline ten- sion edge. Finely gran- ular.



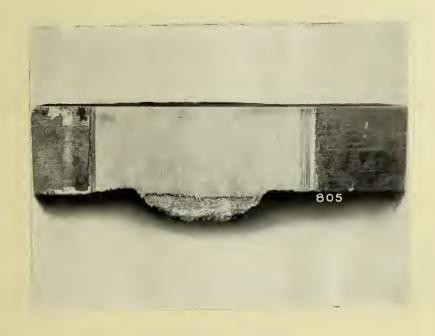


Fig. 48. Thermit Weld Between Two Steel Bars 4 x 8
Inches in Size. View Shows Section Through
Center of Weld. Note the Close Grain
of the Metal and Perfect Fusion
Obtained.



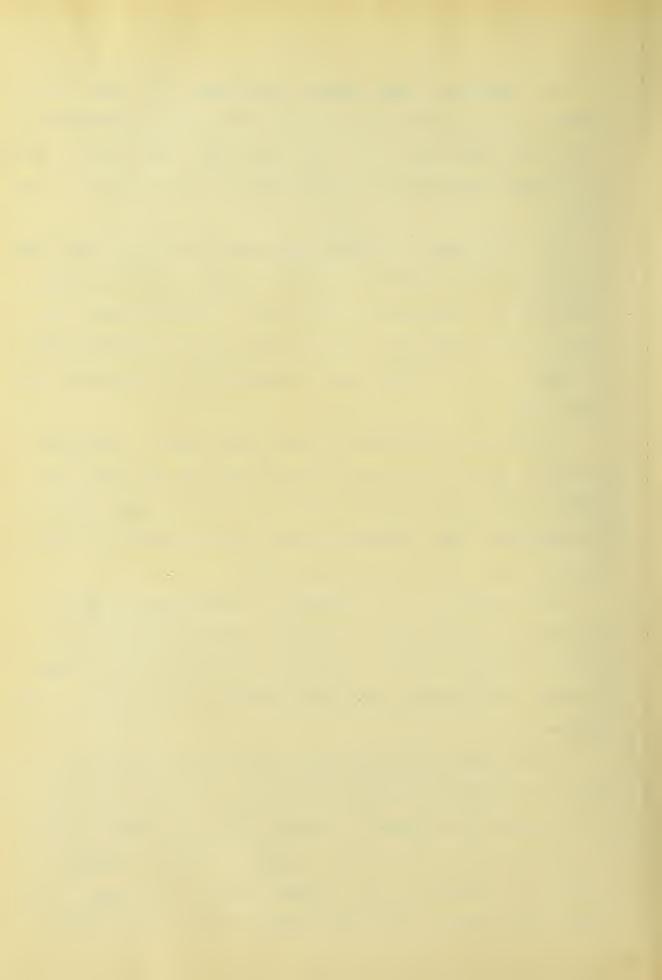
25. Results of Tests Made in the Shops. The tests were made on 1.25 inch soft machine steel. The molds, consisting of 1 part fire clay and 1 part white core sand, were made in halves and clamped together with a thin layer of wet fire clay in between.

Fig. 49 shows the pouring gate and riser in the half mold. The mold clamped together, ready to preheat with the air-gas torch and the weld-bars, are also shown Fig. 50 shows the thermit steel tapped into the mold and the slag overflowing on the floor. Fig. 51 shows the finished weld with the collar and riser still on.

Instead of preheating the steel weld-bars in the mold, they were heated in a forge and inserted into the mold just before tapping the crucible. This saved considerable time in the operation since the molds were baked dry and did not require so long a time to dry and preheat.

There seemed to be a tendency to honey-comb the metal at the edge of the collar. This was probably caused by the great difference of heat in the weld and the portion outside the weld. The fractures were very crystalline especially those unannealed.

In the tests, test bars Nos. 1 and 2 gave a very fine grained cup-shaped fracture with quite a long neck. Weld No. 3 was annealed and turned. It broke in a large blow hole in the weld and gave a very small elongation with no necking. Weld No. 4, annealed but not turned, broke at the edge of the collar with a very crystalline fracture but no honey-combing.



PHOTOGRAPHS TAKEN DURING PREPARATION OF THIS THESIS.



Fig. 49. Crucible, Mold, and Preheating

Torch Ready To Preheat. Steel

Bars To Weld and Half

of Mold Also

Shown.





Fig. 50. Thermit Tapped Into Mold. Metal Flowing
From the Crucible and Slag Overflowing
Onto the Floor.



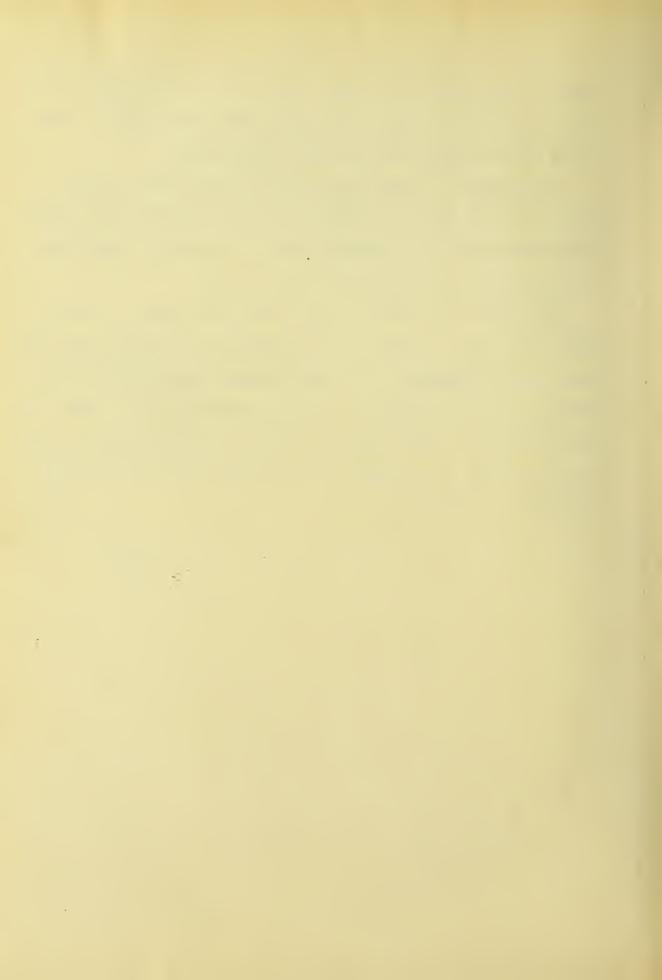
Fig. 51. Weld Made During Test Showing Riser.



Weld No. 5 was left as it was taken from the mold five hours after pouring. It broke 3 1/2 inches from the center of the collar and the fracture was badly honey-combed.

Ten pounds of thermit were used on each weld. Thirty
five seconds after the reaction began the crucible was tapped.
This allowed about 20 seconds after the reaction ceased for the thermit steel to separate from the slag.

In conclusion would say that the tests show: (1) that great care must be taken in the pouring to allow the slag and steel time to separate; (2) that the weld should be properly annealed so that the metal will not crystallize: (3) that the metal should be highly heated and kept hot some distance away from the collar to overcome the injurious effect of the intense local heating.



## TABLE OF RESULTS

	No. 1	No. 2	No. 3	No. 4	No. 5
Kind of bar	Test bar	Test bar	Weld	Weld	Weld
Condition of bar tested	Turned	Not turned	and	Not turned Ann'ld	turned
Dia. in in.	.775	1.246	1.238	1.246	1.246
Area of sec. in sq. in.	.471	1.22	1.202	1.22	1.22
Ultimate Strength in lbs.	21,100	65,600	43,630	48,060	31,200
Stress in lbs. per sq. in.	54,400	53,800	36,200	39,400	25,500
Efficiency of weld #			66.4	72.3	46.7
Total elong- ation in 8 inches	2.36	2.82	.21	.26	None
Per cent elongation	29.5	35.2	2.72	3.25	None

 $<sup>\</sup>frac{\pi}{\pi}$  Average stress of both test bars, 54,600 lbs. per sq. in., used to determine efficiency.





